Artificial Intelligence and Augmented Reality: A Possible Continuum for the Enhancement of Architectural Heritage

ISSN 1828-5961

Roberta Spallone
Roberta Spallone is Full Professor. Chair of REAACH-ID Symposium (with A. Giordano and M. Russo), her recent research links AI/AR with CH. Other fields of her investigation are history of representation and digital technologies for enhancing CH. Author of over 180 publications and invited lecturer in many international conferences.

Valerio Palma
Valerio Palma is Ph.D. candidate in Architecture. History and Project and research fellow in a PoliTo and INWIT partnership project on automatic BIM modeling. He deals with the interaction between digital models and the physical form of the city, and AI and AR app development for CH.

Artificial Intelligence and Augmented Reality: A Possible Continuum for the Enhancement of Built Heritage

Augmented reality and *artificial intelligence* technologies are increasingly involved in the interpretation, classification, and eventually in our understanding of the built environment. This paper collects three recent on-site research experiences, which developed mobile app prototypes and experimented with these advancements in the relationship between computer vision and architectural artifacts. The first project concerns the vaulted atria of Baroque Turin and integrates a work of analysis and representation with augmented reality applications to visualize interpretative 3D models. The second project focuses on the development of a mobile app to access data on monuments, exploiting deep learning technologies for image recognition. The application field is the Imperial Fora in Rome. The third project is part of the so-called "third mission" of universities, being developed in partnership with a company operating in the electronic telecommunications infrastructure sector. The project explores automatic methods for updating existing building information modeling databases on antenna tower sites. This experience, the last in chronological order, though focused on a modern architectural asset, is meant to reframe and integrate the previous ones, updating the methods and the foreseen developments, and stressing the potential of the combined use of the studied technologies. The joint consideration of the three projects is aimed at reflecting on the processes, which from different techniques for the recognition of spatial features, produce schematic understanding and operational uses of the shape of built heritage.

Keywords:
Artificial Intelligence; Augmented Reality; Survey; Modeling; Built Heritage

DOI: https://doi.org/10.20365/disegnarecon.26.2021.16

1. INTRODUCTION

Artificial intelligence (AI) and augmented reality (AR) are revealing the potential of their applications within a broadening scope, including the field of built heritage (BH).
These technologies demonstrate to be best exploited when their application, together with other information and communication technology (ICT) advancements, achieves a continuum. Their combination and their smooth interaction with digital surveying and information modeling can fuel new knowledge models and communication systems aimed to enhancing the built environment.
This proposal collects some recent fieldwork, that is, research experiences involving the development of prototypes and experiments with these technologies, to which (to an increasing extent) we entrust the interpretation, classification, visualization, and eventually our understanding of the built space.
The first project is based on previous research on the vaulted atria of Baroque Turin, which produced the documentation of over 70 sites and the study of the geometric components of the vaults through digital models. The project aims to explore the integration of AR and digital archives for built-space related information.
The second project is focused on the Central Archaeological Area in Rome and deals with the use of deep learning techniques in developing services for accessing digital information on archeological sites.
The third project, currently ongoing, goes further in investigating the operational impacts of AR-AI integrated systems. As part of the so-called "third mission" of universities, the project is carried on through a framework agreement involving a company operating in the wireless network infrastructure sector. The project expands the authors' interest in the field of common and quite standardized architectural-scale artifacts and has the following objectives: (1) the study of an automatic methodology to update an existing building information modeling (BIM) project or to create a new one, through computer vision applications; (2) the development of change-detection techniques suitable for the studied sites; (3) the creation of an *app* that allows even non-experts users to perform a correct digital survey of the site using a mobile device, employing said methods and techniques.
The latter experience, though apparently unrelated to the heritage values encompassed by the previous cases, is in fact a chance to elaborate the proposed methods in order to cope with the management phases of the artifact, even when dealing with architectural heritage.
The joint consideration of these research experiences is meant as an opportunity to reflect on the processes that, from techniques for the recognition of spatial features such as AR and AI, produce a schematic understanding and operational uses of the built form. The technologies that are learning to interact with heritage, architecture, and the ever-growing amount of related information can use the tangible aspects of architecture — even in a reality pervaded by virtuality — as a common key for sharing knowledge.

2. STATE OF ART

While AI and AR technologies are now widely used, they are taking their first steps in the field of BH, and much investigation into their role and mutual connections is still required. AI advancements, and specifically DL, enable many applications for computer vision, thanks to graphic computing capabilities and the availability, for many fields, of large image datasets. Interest in the interaction between DL and the built environment has recently increased — e.g., in the development of self-driving cars (Cordts et al., 2016) — but only a few studies delve into the use of these technologies for the interpretation of architecture, urban space and BH in general (Ma et al., 2019).
DL can also be used to process remote sensing and metric survey data (e.g., point clouds) by automatically generating mathematical and semantic interpretations of built elements (Barazzetti and Previtali, 2019; Teruggi et al., 2020; Ma et al., 2019) provide a review of DL applications in remote sensing, pointing out a range of tasks spanning from image classification and object detection to segmentation, both for images and 3D data, exploiting supervised as well as unsupervised training. Among the applications at the architectural scale, and specifically in the BH context, Pezzica et al. (2019) use of DL for object detection of detail elements from historical building imagery; Morbidoni et al. (2020) perform point cloud semantic segmentation to identify common architectural elements such as columns, doors, moldings and vaults; Barazzetti and Previtali (2019) use neural networks to acquire data for parametric geometries, producing an analytical approximation of a vault surface given point cloud data.
AI applications for heritage applications are not limited to visual data processing. Cultural Heritage (CH) institutions and research teams are employing and integrating different techniques in cataloguing and describing digital objects — such as texts, videos, audio tracks, and of course pictures — through metadata creation and data linking (Kaldeli et al., 2021).
The main hurdles faced in the application of DL techniques to the BH are still due to lack of training (for supervised models) and benchmarking data sets, especially when dealing with domain specific categories and limited physical samples, such as CH and historical architecture (Ma et al., 2019; Pezzica et al., 2019).
Alongside the broader domain of *mixed reality* (Milgram and Kishino 1994), Augmented Reality (AR) has been extensively experimented and studied over the past two decades and has spread an established component of Cultural Computing (Greengard, 2019; Bekele et al., 2018).
AR provides intuitive methods to access space-related information, by superimposing digital contents on real-world images (Amin and Govilkar, 2015). Nowadays, AR can work on most mobile devices, and allows the tracking not only of markers and images, but also of 3D objects (Younes et al., 2017). Therefore, AR is interacting with an increasingly large and complex environment and the potential applications related to architecture and the built environment also beginning to

DOI: https://doi.org/10.20365/disegnarecon.26.2021.16

ISSN 1828-5961

Fig. 1 - Samples of the objects studied in the three presented projects: (a) atrium of Palazzo Birago di Borgaro, Turin (Filippo Juvarra 1716); (b) Temple of Castor and Pollux, Rome (1st century CE); (c) base radio station, detail. Photos by M. Vitali, R. D'Autilia, ~Pyb (CC BY-SA 4.0, cropped).

emerge. In the construction sector, AR shows advantages in effectively solving a variety of construction management issues (Ahmed, 2019; Li et al., 2018), and can be adopted in design and data visualization, project scheduling, progress tracking, worker training, safety management, time and cost management, and quality management. Yet, despite the research on the benefits of these technologies, their actual adoption is not widespread.
In the field of CH, AR is considered an enabling technology: studies agree that it favors CH accessibility by linking digital information to real space (Panou et al., 2018; Bekele et al., 2018). In their extensive review of immersive reality technology for CH Bekele et al. (2018, p.4) state that "*flexibility, immersion, interaction, coexistence, and enhancement are the essential aspects of a mixed reality experience*". AR can be used in tourism to enhance the user experience by developing virtual tour guides and novel storytelling solutions (Luigini, 2019).
In these days AR is constantly updating its feature and use modes, thanks also to steps forward in dedicated hardware and software as commercial products. The main issue that still prevents a coherent ad widespread adoption of this technology is partly related to these high-paced changes: *standardization* is still limited, and this affects scalability, interoperability, and the robustness of the tracking features — which rely on many different sensors (Bekele et al., 2018).
In summary, despite the large number of experiments and studies involving AR and AI, cases are far from proposing a general approach to these technologies in BH management. As a consequence, many innovative applications, though proving effective, are not shaping our knowledge models.

3. THREE CASE STUDIES: CONNECTIONS AND METHODOLOGY

This paper focuses on experiments that link AI and AR to the analysis, interpretation, and communication of the built environment, carried out in the last two years. It is evident that the rapid development of technologies involves the digital world in its entirety and concerns devices, software, archives, and our way to process and store data through these tools. From this point of view, the three case studies can be considered as research areas open not only to integrations, but also to corrections in the methodological and operational strategies.
The first case connects AR and the complex of unitary atria in the palaces of Baroque Turin (fig. 1, a). The second case applies deep-learning image recognition in the Central Archaeological Area in Rome (fig. 1, b). The last project exploits both AR and AI to interact with the widespread infrastructure system for modern wireless telecommunications (fig. 1, c).
The third, ongoing case represents the current status of the research stream. Thus, the previous experiences are discussed not only taking into account the specific progress of each project, but also in the light of the new solutions evaluated during the last one. The case studies concern very different categories of BH — either from the historical, morphological, and functional point of view — resulting in different users, ways, and purposes of use. Despite the marked ontological differences of this last case compared with the prior ones, many of the advancements already achieved are usefully employed also in the research on contemporary artifacts. Furthermore, as it will be emphasized, the new methods and techniques being tested may impact the development of previously examined cases.
Of course, the cognitive and informative legacy

DOI: https://doi.org/10.20365/disegnarecon.26.2021.16

ISSN 1828-5961

to be connected with the physical space is very different when changing the object and context studied. Hence, we should consider the three cases as complementary experiences and aim at comparing, correcting, and integrating the different results. Common to all these experiences is the interpretation of the physical space and the architectural, urban, and infrastructural structures that populate it as the shared access key to our knowledge of the asset, and as a means for navigating through multiplying levels of analysis and information.
The choices of the digital tools made by the authors have been oriented towards criteria of sustainability of the projects and their developments, preferring free and open-source software (FOSS), or in any case free software, to contain implementation costs and favor the interoperability of the results. The orientation in the choice of devices for the fruition and, in the last case, the validation of data, is also based on the ease of use and the availability of low-cost tools. Therefore, we oriented the projects towards a *mobile first* approach, developing applications that are compatible with Android and iOS operating systems. This issue has become particularly sensitive in the last year when the pandemic emergency stressed the opportunity to use personal devices as a tool to reduce the risk of contagion. Moreover, the use of smartphones favors the equally important tracking and interpretation of flows that, even after the emergency has passed, will allow rational management of space and time at cultural sites, and will soon exploit the 5G technology. The multimedia content produced by users during visits can also be immediately shared on web platforms that collect this knowledge on BH. In this regard, the first two cases make use of the *[cult]* database and web interface (Cecchini et al., 2019; Bortot et al., 2017), a platform to manage multimedia information for architecture-related data, while the last one uses a corporate platform, currently under development.
The specific methods adopted in each project will be further discussed in the next paragraphs.

4. CASE STUDY: AR ENHANCEMENT OF CULTURAL TOURISM SITES

The first case study, on the subject of unitary atriums in Baroque Turin, is one of the results of a ten years' research, which has recognized and catalogued over seventy entrance halls in seventeenth- and eighteenth-century palaces and houses (fig. 2). The interest and uniqueness of these "open structures" (Pommer, 1967) and their extensive diffusion (Norberg-Schulz, 1980) have been highlighted. These widespread artifacts, which formerly were the fulcrum of the ceremonial route to the palace, are currently used for different functions and are accessible to the public (mostly within given opening hours), but they are little known, even to the citizens.
The vaulting systems that characterize the atria in their varied formal and constructive composition have been classified as "star-shaped" vaults, "planterian" vaults (named after their inventor, Gian Giacomo Plantery) and "banded" vaults (fig. 3). These were designed by internationally renowned architects — such as Guarini, Juvarra, Vittone — and lesser-known figures who contributed to the definition and diffusion of these typologies — such as Garove, Baroncelli and Plantery, but also and above all by unknown

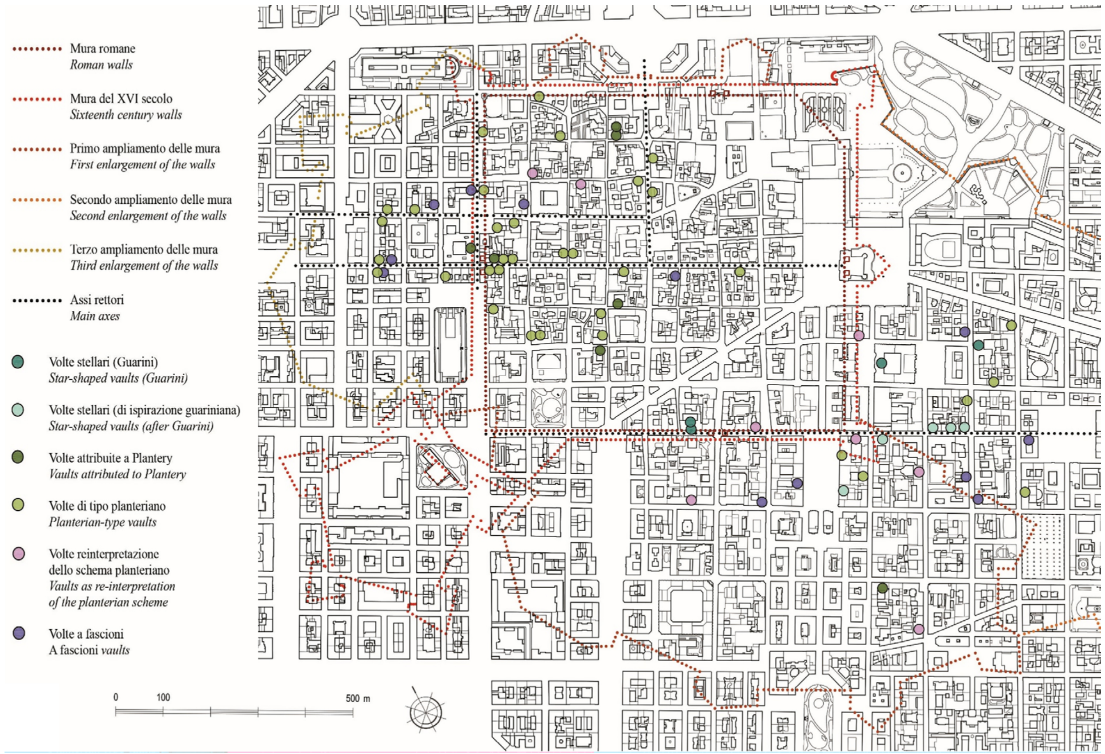
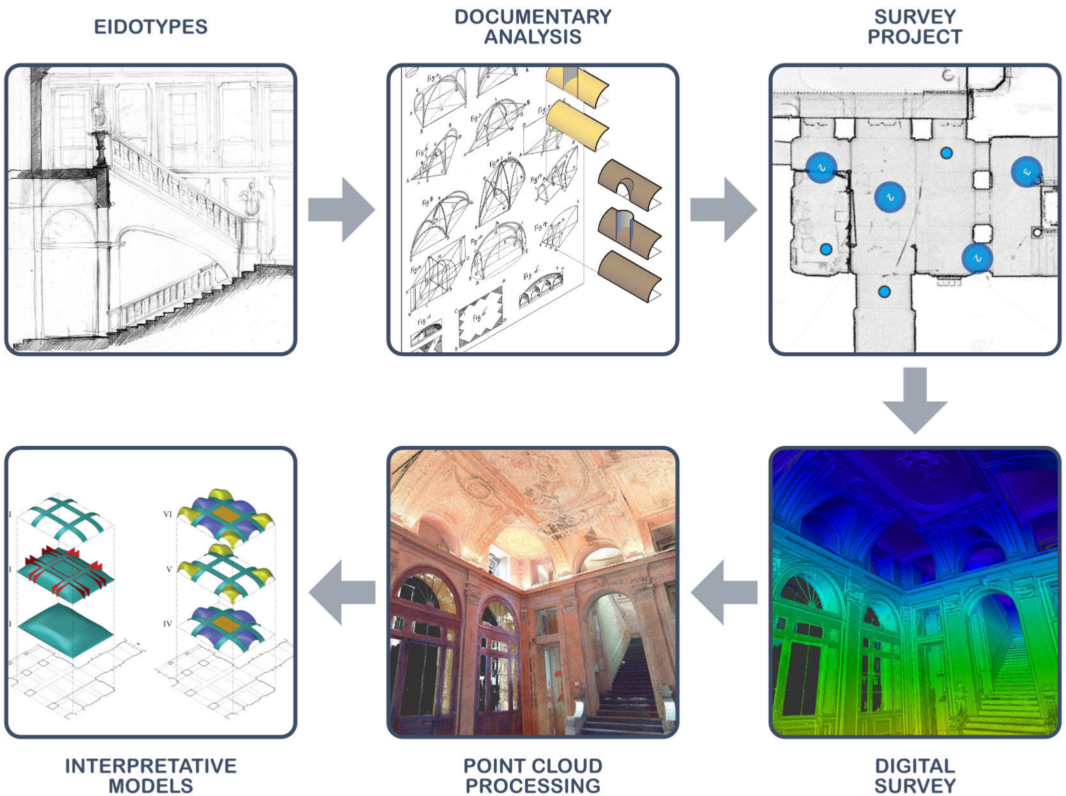


Fig. 2 - Unitary atriums in Baroque Turin. Editing: M. Vitali.

DOI: https://doi.org/10.20365/disegnarecon.26.2021.16

Fig. 3 - Star-shaped vault (Palazzo Asinari di San Marzano, Garove 1684), planterian vault (Palazzo Cavour, Plantery 1729), and banded vault (Palazzo Martini di Cigala, Juvarra 1716). Photos by M. Vitali.

Fig. 4 - Workflow for the analysis of unitary atriums. Illustration by R. Spallone.



architects. The value of these spaces emerges from their configuration as a system within the historic urban fabric. This led to the possibility of creating thematic tourist routes, because the recognition of their value by the community can fuel virtuous phenomena of active protection. What immediately followed was the idea that these routes could make use of digital innovation for communication, use and interaction with the public (Palma, Spallone, Vitali, 2019a). The knowledge data produced during the research [1] ranged from digitized archival and bibliographic documents, to point clouds created using laser scanning technologies, to digital drawings and models, the latter aimed at recognizing geometric references in the design of the vaulted surfaces and their hierarchy (fig. 4).

Current research developments, aimed at going beyond the visible, are examining wall textures covered by plaster and stucco through thermographic surveys. All these materials, the implementation of which is clearly far from complete, can be collected in the *[cult]* platform and related services, according to an ontology model that has already been studied in detail (fig. 5) (Palma, Spallone, Vitali, 2019b).

After a review of the solutions available on the market, it was decided to develop an app for Apple mobile platforms, based on the ARKit software development kit (SDK). The 3D object recognition and tracking functions on which these and similar AR tools are based involve simultaneous location and mapping (SLAM) systems, which allow a rapid 3D survey of the environment and calculation of the observer's position (Younes et al., 2017; Linowes & Babilinski, 2017). In the case of ARKit, this is achieved using camera images and data from other sensors such as the phone's inertial platform (some newer devices even have LIDAR sensors). Unlike many of the systems already available today, the tools adopted in the early stages of the project (early 2019) were not designed to track large objects, but were beginning to present the flexibility to conduct the first experiments at the architectural scale. The chosen system required the preliminary acquisition of sparse point clouds of the objects to be recognized, to be compared with the environment surveyed at runtime. For this task, a demo app pro-

DOI: https://doi.org/10.20365/disegnarecon.26.2021.16

duced by Apple was used and adapted to the needs of the project — for example, getting to capture points at a greater distance. When the object is recognized, the app obtains a reference point for positioning the virtual objects to be displayed. In this case, it was chosen to show the geometric reconstructions of the atrium vaults. The system was tested for the four atria of the palaces Carignano, Novarina, d'Arcour and Coardi di Carpenetto. Small portions of the architectural space with a lot of plastic details (e.g., the base of the columns) were used as anchoring models, which, thanks to SLAM techniques, allowed the visualization of the 3D model even when not framed. The stability and accuracy of the positioning of the digital layers proved to be adequate for the level of detail of the geometric reconstructions shown (fig. 6-7).

5. CASE STUDY: DEEP LEARNING MONUMENT RECOGNITION

The second case concerns the integration of information services for tourism in urban areas and sites of architectural and archeological interest, employing image recognition functions enabled by DL. The project, the technical aspects of which have been explored in previous publications (Palma, 2019; Andrianaivo et al., 2019), was developed as part of the activities of the F*UL*L Interdepartmental Center of the Polytechnic of Turin and involved several external partners [2].
The problem of optimizing investments in CH is the basis of the project and arises by noting the inconsistency between the nodal importance, in Italy, of tourism linked to this heritage and the small amount that the country allocates to culture (cfr.

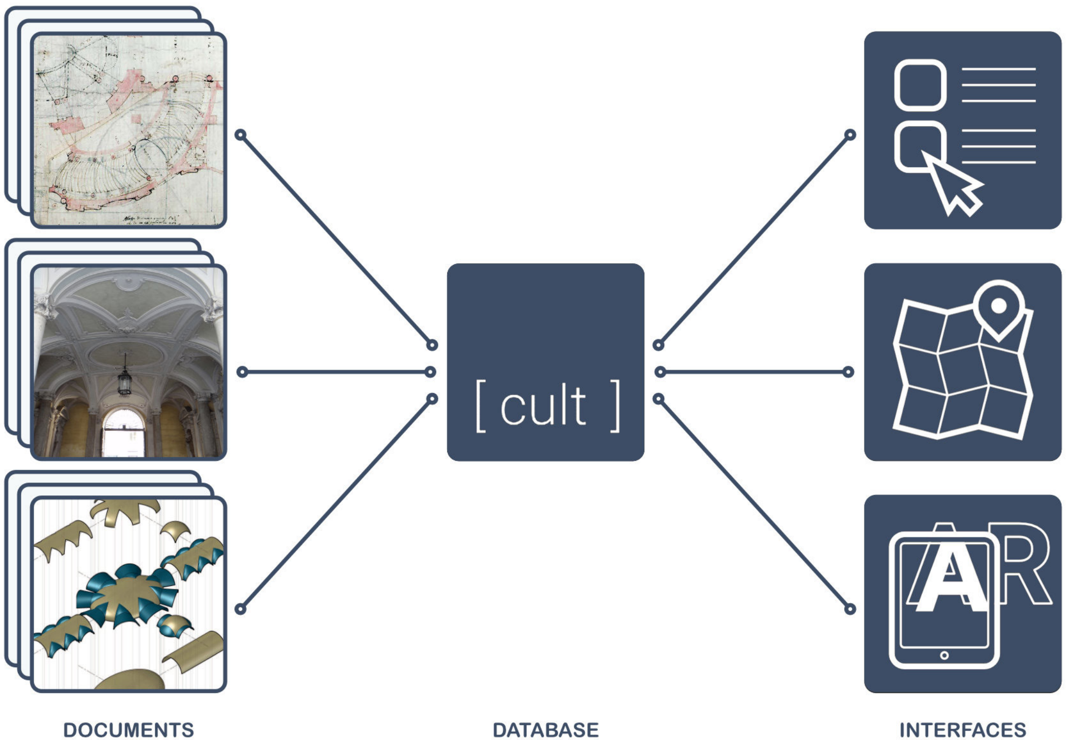


Fig. 5 - Scheme of the interaction of the project with the digital archiving tool *[cult]*. Illustration by R. Spallone, V. Palma.

Fig. 6 - Scanning of target object features and superimposition of 3D models in the palaces d'Arcour and Coardi di Carpenetto. Illustration by V. Palma.

DOI: https://doi.org/10.20365/disegnarecon.26.2021.16

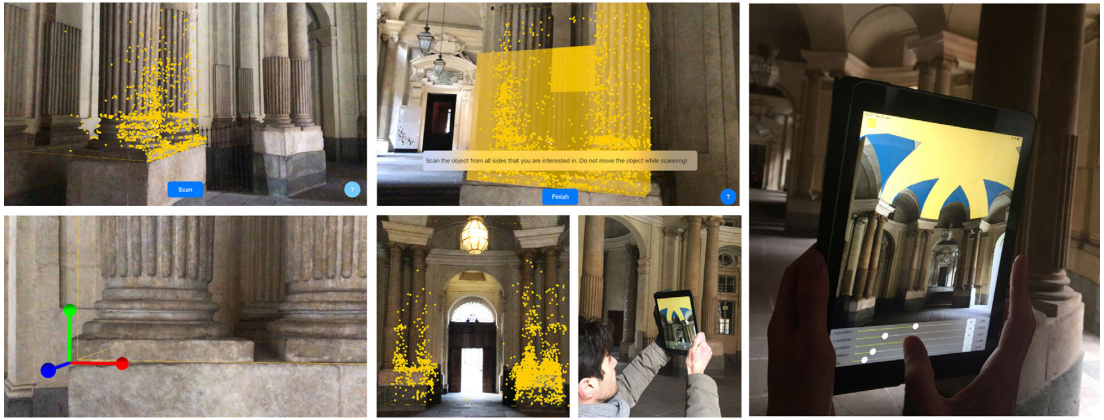


Fig. 7 - AR workflow in Palazzo Carignano: definition of the bounding box, scanning of target objects features, positioning of reference system origin, superimposition of 3D model in the visualisation app. Illustration by V. Palma.

Fig. 8 - Examples of monument of the Central Archeological Area in Rome showing different size and conservation status. From top left, clockwise: *Umbilicus urbis Romae*, *Domus Augustana*, Temple of Antoninus and Faustina, *Aedes Concordiae*. Photos by R. D'Autilia.

Eurostat, 2021). We aim to exploit information and communication technology (ICT) to define new information access and management strategies for BH sites.

The proposed solution is based on the integration of computer vision technologies and extensive digital information archives. The latter are often already available on cultural sites as material produced for research purposes or for web based remote-access services. The developed application can replace services such as audio guides, but also more recent systems, such as QR codes. Using an image recognition algorithm suitable for the many mobile devices, the app allows the creation of an information service without a dedicated physical infrastructure, and therefore flexible, not perishable, easily upgradeable, and inexpensive.

On the one hand, the categories of cultural venues that can take advantage of this solution include minor sites. These, due to limited tourist flows, may not afford the installation and management of physical devices. On the other hand, sites that host many visitors could benefit of better targeted services and less maintenance costs. This is the case of the first site on which the app was tested, namely the Central Archaeological Area of Rome, which includes the Imperial Fora. The area can attract over 7 million visitors a year (data prior to the health emergency, cfr. MiBACT, 2021) and hosts a great variety of monuments of different sizes and in various states of conservation (fig. 8).

The app is developed as a tool that tourists can use to understand the visited environment quickly and easily, and as a service that can be updated frequently, translated, and adapted to many user categories. The software (running on Apple iOS platforms) features real-time image recognition functions based on the images of the device's camera. More specifically, *convolutional neural networks*, a class of DL models widely used for computer vision and including models optimized for mobile devices, were used. The development of the algorithm was initiated on the basis of a pre-trained MobileNet model (Howard et al., 2017). The tools used include the Xcode development interface by Apple and the open-source libraries TensorFlow and Keras for the Python programming language.

The image dataset to train the AI model to recognize monuments was created through a photographic survey (50-100 images for each monument). The prototype proved capable of effectively recognizing 46 monuments, in different light conditions and from many viewpoints. One of the most relevant aspects of this result concerns the small size of the recognition engine, which takes up only 13MB of disk space, being also suitable for an offline use.

The app connects each recognized object to a set of data by leveraging the database and web services of the *[cult]* CH documentation platform (fig. 9). The information that the prototype allows to consult from the device includes: images, mainly photographic; texts, oriented to tourist use; three-dimensional models, in particular representing the hypothesis of reconstruction of the monuments; the geographical position of the object, described as a point or a polygon in spatial coordinates; other schematic data such as the era to which the monument dates back.

The tool can be easily scaled and transferred to new sites. Within the project, this flexibility was also demonstrated through a second application field, namely the historic center of the city of Turin (about 80 monuments), which made it possible

DOI: https://doi.org/10.20365/disegnarecon.26.2021.16

to expand the variety of recognizable artifacts and to adapt the app to a different digital archive, managed by the Municipality [3].

6. CASE STUDY: SEMI-AUTOMATED BUILDING INFORMATION MODELING

The third project, currently in progress, shifts the focus to contemporary artifacts. INWIT, the industrial partner of the project, is the first wireless network operator for mobile telephony in Italy and manages an asset consisting of telecommunications antenna towers and related equipment. Recently, the company has started the process of digitizing this asset, using building information modeling (BIM) and a web server to access models and data [4]. The partnership involves creating the prototype of an app for mobile devices to support maintaining the sites and interacting with the recorded information. The main objective is to allow the continuous updating of the models, due to the frequent alterations of the on-site condition, especially regarding antennas and other electronic equipment.

The team is working on solutions that highlight the opportunities offered by the AR and AI tools already explored with previous experiences. At the same time, new possible application enabled by the rapid advancement of technologies are tested. The aim is to define an effective recognition process to be applied to the equipment present on the sites, to access any corresponding entry in the database. In this way, an operator can check and change the parameters inside the BIM model, possibly create a new element, or delete one that has been removed from the site. Therefore, the app should show the geometric component of the model and facilitate its comparison with reality.

The planned experiments will test object-tracking AR functions based on both CAD models and point clouds, to evaluate and compare their reliability and stability. In particular, it will be crucial to verify whether the different configurations of the sites (or relevant subsets of the equipment) are suitable to generate effectively recognizable models. Furthermore, hardware requirements to ensure the smooth operation of the system should be pointed out. Some environmental variables are also important, including lighting conditions: insufficient lighting, reflections, excessive contrast with the background (e.g., *contre-jour* images), poor contrast (e.g., uniform surfaces) can hinder the correct recognition of the target.

The sites managed by the company fall into many different types and categories, but the project will focus on a sample characterized by a low height of the antenna towers, given that the survey will take place from accessible levels without special equipment (and therefore climbing on the structures will not be considered). The main structures to be analyzed are therefore poles and small lattice towers that are mainly located in rooftop sites. The other equipment present on the sites includes cabinets, prefabricated buildings, shelters for electrical equipment, distribution boards, and power stations. Boards and power stations, as well as antennas, are the categories considered in planning the research work. Indeed, these

Fig. 9 - Main views of the monument recognition app. Photo: Andrew and Annemarie (CC BY-SA 4.0, edited). Illustration by V. Palma.

ISSN 1828-5961

objects are more relevant in terms of presence, frequency of updating, and standardization (useful to set up a parametric representation).
The app will allow the "navigation" of the database from inside the real space. The interface will support query functions of specific elements to access editing functions (fig. 10). Given an element of the selected BIM model, the app will let the user modify some parameters — e.g., the orientation of an antenna or the number of sub-components contained in a distribution board (switches, alternators...). Depending on the type of parameters to be modified, the interface may include other AR applications (e.g., measurement functions), but also AI tools or simpler systems for entering text, numerical values, or preset options. Image recognition functions (i.e., recognition of the entire frame, mentioned in the previous project) and object detection (i.e., identification of multiple elements within a single image), based on DL, will be evaluated for the automatic assignment of categories to the elements (e.g., to add a new antenna to the model, or to identify and count the instances of a specific sub-component within an electrical panel) (LeCun et al., 2015; Pezzica et al., 2019).
At present, the project team has addressed the feasibility of the proposed user interface solutions and has conducted studies and experiments on the tools to be adopted. For the AR functions, the integration of Unity and Vuforia has been evaluated, and we plan to exploit the Vuforia functions called *Model Targets* and *Area Targets*, which allow the use of CAD models and point cloud models (which INWIT is planning to produce) respectively, as objects to be recognized and tracked (PTC Inc., 2020). Besides, the software allows loading at runtime a database of recognition models. This will make the app scalable and adaptable to the large number of sites, estimated in thousands, that the company would manage through the tool. For AI applications, the Keras and TensorFlow libraries will be used.
The subsequent phases of the project will deal with creating a prototype consistent with the outlined scheme of connections between asset characteristics and the database. As shown in fig. 11, the scheme specifies which technologies and interface solutions the app should employ to interpret real objects and set the parameters for the model.

Fig. 10 – Example of planned model selection methods: searching an element by identification code (top), selection from model browser (bottom). Illustration by V. Palma.

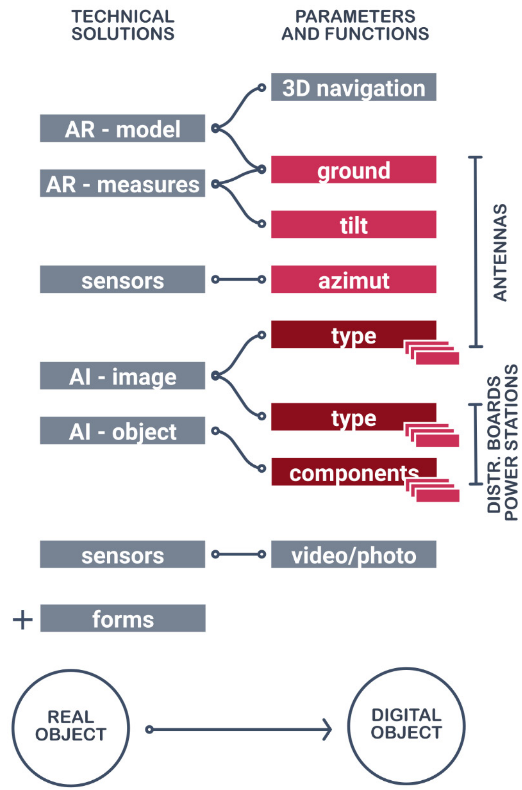


Fig. 11 – Graph of the planned data processing tools to populate the database underlying the BIM model. Different technical solutions can interpret the real object to obtain parameters for the digital object and the visualization and documentation functions. Illustration by V. Palma.

7. OPEN ISSUES AND FUTURE CHALLENGES

The first two projects are conceived within a broad framework of research issues. The first case investigates the understanding of potential AR applications at the architectural scale, while the second project emphasized the need for a smooth and consistent flow of relationships between the real world and information models. However, at the

DOI: https://doi.org/10.20365/disegnarecon.26.2021.16

present stage of progress, the research conducted in these cases has only achieved partial results. The AR project was focused on the dissemination of an information asset already built on a limited set of Baroque architecture. Therefore, attention to the scalability of the proposed application was limited. From the side of the documentary information, access to a web database was considered. On the contrary, as regards the flexibility of the AR part, an alternative solution to saving the target models on the device has not been proposed, binding the result to the single application proposed. Instead, for the automatic recognition of monuments, a flexible technological framework to update the current information services and self-guided tours in cultural sites has been defined, as demonstrated by the replication of the experiment in the historic center of Turin. However, the project was not focused on the effectiveness of the tool in accessing and communicating complex documentary research, leaving these developments at a hypothetical stage.
The third project is a testbed for the interaction between AR and AI, and for a closer communication with spatial information archives. The first two projects, still considered ongoing and open to new advances, can be reformulated in the light of this experience and the relevant technological changes that have taken place.
Developments in the project on Turin Baroque atria plan to extend the application to a wider number of cases and visualization functions, to include AR experiences within thematic routes for cultural tourism at the urban scale. These objectives present technical and conceptual challenges related to the accuracy and fluidity of AR solutions, to the communication of mobile devices with information databases — which, for scalability purposes, should also include information for the correct anchoring of digital layers on the real world — and to the organization of this knowledge, according to the new modes of access and effective use of the tools. In this sense, the recent experience on modern architecture can lead towards adopting BIM for historical architecture (or HBIM) and has begun to speculate on strategies for making many target models available on mobile devices from a remote server. During the preliminary study of the tools to be adopted, this possibility proved to be compatible with the Vuforia and Unity software.
Further developments of the project will also include integration with technologies dedicated to the detection and anonymous tracing of flows, to favor the optimization of routes, also on the basis of the preferences of the public, and allow the control and regulation of access. Hence, a foreseeable expansion of the project may concern the construction of a system of recommendations aimed at informing users about facilities and cultural opportunities offered in the surrounding area.
As for the project on AI monument recognition, foreseen developments concern the updating of datasets and the exploitation of other computer vision techniques. Object detection, now being tested on the telecommunications infrastructure, would allow identifying not only single objects and monuments but categories of architectural objects, such as construction elements, decorative characters, and building types (Pezzica et al., 2019). A key contribution in the field of architectural heritage research could derive from the production of training datasets to support benchmarking and the development of similar solutions, also through *transfer learning* functions — that is, the use of knowledge developed by a system of AI in a new application context (Ma et al., 2019; Pezzica et al., 2019). Comparing different results, covering both historical and contemporary architecture as provided by the ongoing projects, could offer a broader understanding of the effectiveness and bottlenecks related to recognition algorithms and training pipelines.
Furthermore, with the development of internet-of-things technologies (Fuller et al., 2020), we can expect advancements in integrating the information apps with services related to physical infrastructure. This potential evolution of the offered services was considered in the drafting of all the described projects, alongside the aims to contain costs and increase accessibility (not only to data but also to physical assets) by reducing the staff required to monitor the sites and manage visits.

8. CONCLUSIONS

This paper presented a series of three connected research experiences dealing with AR and AI technologies applied to the built environment through mobile app prototyping — especially AR using model targets at the architectural scale and DL algorithms for image recognition. The first two experiences took BH as a field of study and employed AR and AI separately. In the first case, AR proved an effective means to enhance the accessibility and understanding of heritage documentation and 3D interpretative models, though the scalability of the system has not been validated. In the second case, AI has been used as an alternative to widespread traditional and digital solution for self-guided tours, allowing monument recognition in archeological and urban sites and the connection to web archives and services. Compared to the first project, the connection with detailed documentary research was studied to a lesser extent, focusing on the flexibility of the tool.
The third experience described is an ongoing study on managing a contemporary infrastructure by means of BIM and computer vision. This project is discussed as a chance to reframe and integrate the understanding of AI and AR tools in architecture and the methods defined through previous experiences. Furthermore, the test of recent technological advancements is planned, also foreseeing new developments of the BH-related projects. AI and AR can be combined to use the architectural form as a key, or a shared layer, to access structured spatial databases, such as BIM. In this sense, future research on the potential of computer vision should address the relationship between the categories we adopt when representing and interpreting the built environment and how these tools can effectively use the same abstractions [5].

DOI: https://doi.org/10.20365/disegnarecon.26.2021.16

ISSN 1828-5961

NOTE

[1] The research group initially was composed of Roberta Spallone and Marco Vitali. In 2019 María Concepción López González (Universitat Politècnica de València) joined the group thanks to the international project "Nuevas tecnologías para el análisis y conservación del patrimonio arquitectónico" (funded by the Ministry of Science, Innovation and the University of Spain), and carried out laser scans of numerous case studies. In this occasion the research group grew with PhD students Giulia Bertola, Fabrizio Natta and Francesca Ronco. In the same year, the collaboration with Valerio Palma started with the realization of the project reported in this paragraph.

[2] The team working on the project at F*U*LL | The Future *Urban Legacy* consisted of Matteo Robiglio, Claudio Casetti, Francesca Frassoldati, Louis N. Andrianaivo e Valerio Palma. The project was carried out in partnership with Roberto D'Autilia. The ICEA department of the University of Padua made available its servers and the *[cult]* service to build the first version of the app.

[3] MuseoTorino (museotorino.it) made available its data and the API to build the app version for the historic center of Turin.

[4] In the framework agreement between INWIT and Politecnico di Torino for the implementation of Research Projects, the project "Modellizzazione BIM automatica" started at the end of 2020. The team supervising the project at INWIT is composed by Luca Capozucca, Giulia Cicone, Gianpiero Lops, and Roberto Rinauro. The project is funded by INWIT. The research team of Department of Architecture and Design at Politecnico di Torino is composed by Roberta Spallone (supervisor) and Valerio Palma (research fellowship holder).

[5] Roberta Spallone wrote paragraphs 1, 3, 4; Valerio Palma wrote paragraphs 2, 5, 6, 8. Roberta Spallone and Valerio Palma wrote paragraph 7.

REFERENCES

Ahmed, S. (2019). A Review on Using Opportunities of Augmented Reality and Virtual Reality in Construction Project Management. *Organization, Technology and Management in Construction: An International Journal*, 11(1), 1839–1852.

Amin, D., & Govilkar, S. (2015). Comparative Study of Augmented Reality SDK's. *International Journal on Computational Science & Applications*, 5(1), 11–26.

Andrianaivo, L. N., D'Autilia, R., & Palma, V. (2019). Architecture recognition by means of convolutional neural networks. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-2-W15, 77–84.

Barazzetti, L., & Previtali, M. (2019). Vault modeling with neural networks. I*SPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-2/W9, 81–86.

Bekele, M. K., Pierdicca, R., Frontoni, E., Malinverni, E. S., & Gain, J. (2018). A Survey of Augmented, Virtual, and Mixed Reality for Cultural Heritage. J*ournal on Computing and Cultural Heritage*, 11(2), 1–36.

Cecchini, C., Cundari, M. R., Palma, V., & Panarotto, F. (2019). Data, Models and Visualization: Connected Tools to Enhance the Fruition of the Architectural Heritage in the City of Padova. In C. L. Marcos (Ed.), *Graphic Imprints* (pp. 633–646). Cham: Springer International Publishing.

Cordts, M., Omran, M., Ramos, S., Rehfeld, T., Enzweiler, M., Benenson, R., Franke, U., Roth, S., & Schiele, B. (2016). The Cityscapes Dataset for Semantic Urban Scene Understanding. *2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, 3213–3223.

Eurostat (2021). *Government expenditure by function for European Union (27 countries), 2018 (% of GDP)*. In *COFOG*. Retrieved February 25, 2021, from https://ec.europa.eu/eurostat/cache/infographs/cofog/

Fuller, A., Fan Z., Day C., & Barlow C. (2014). Digital Twin: Enabling Technology, Challenges and Open Research. ArXiv:1911.01276 [Cs], January 21, 2020.

Greengard, S. (2019). *Virtual reality*. Cambridge: Mit Press.

Howard, A. G., Zhu, M., Chen, B., Kalenichenko, D., Wang, W., Weyand, T., … Adam, H. (2017). MobileNets: Efficient Convolutional Neural Networks for Mobile Vision Applications. *CoRR*, abs/1704.04861.

Kaldeli, E., Bekiaris, S., Menis-Mastromichalakis, O., Ralli, M., Tzouvaras, V., & Stamou, G. (2021). CrowdHeritage: Crowdsourcing for Improving the Quality of Cultural Heritage Metadata. *Information* 2021, 12, 64.

Li, X., Yi, W., Chi, H.-L., Wang, X., & Chan, A. P. C. (2018). A critical review of virtual and augmented reality (VR/AR) applications in construction safety. *Automation in Construction*, 86, 150–162.

Linowes, J., & Babilinski, K. (2017). *Augmented reality for developers: Build practical augmented reality applications with unity, ARCore, ARKit, and Vuforia*. Birmingham: Packt Publishing Ltd.

Ma, L., Liu, Y., Zhang, X., Ye, Y., Yin, G., & Johnson, B. A. (2019). Deep learning in remote sensing applications: A meta-analysis and review. *ISPRS Journal of Photogrammetry and Remote Sensing*, 152, 166–177.

MiBACT (2021). *Visitatori e introiti di Musei, Monumenti e Aree Archeologiche Statali*. In *MiBACT – Ufficio di Statistica*. Retrieved February 25, 2021, from http://www.statistica.beniculturali.it/Visitatori_e_introiti_musei.htm

Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE TRANSACTIONS on Information and Systems*, 77(12), 1321–1329.

Morbidoni, C., Pierdicca, R., Paolanti, M., Quattrini, R., & Mammoli, R. (2020). Learning from Synthetic Point Cloud Data for Historical Buildings Semantic Segmentation. *Journal on Computing and Cultural Heritage*, 13(4), 1–16.

Norberg-Schulz, C. (1980). *Architettura Tardobarocca*. Milano: Electa.

Palma, V. (2019). Towards deep learning for architecture: A monument recognition mobile app. *ISPRS - International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-2/W9, 551–556.

Palma, V., Spallone, R., & Vitali, M. (2019a). Augmented Turin baroque atria: AR experiences for enhancing cultural heritage. I*SPRS - International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-2/W9, 557–564.

Palma, V., Spallone, R., & Vitali, M. (2019b). Digital Interactive Baroque Atria in Turin: A Project Aimed to Sharing and Enhancing Cultural Heritage. In A. Luigini (Ed.), *Proceedings of the 1st International and Interdisciplinary Conference on Digital Environments for Education, Arts and Heritage. EARTH 2018* (Vol. 919, pp. 314–325). Cham: Springer International Publishing.

Panou, C., Ragia, L., Dimelli, D., & Mania, K. (2018). An architecture for mobile outdoors augmented reality for cultural heritage. *ISPRS International Journal of Geo-Information*, 7(12), 463.

Pezzica, C., Schroeter, J., Prizeman, O. E., Jones, C. B., & Rosin, P. L. (2019). Between Images and Built Form: Automating the Recognition of Standardised Building Components Using Deep Learning. *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences*, IV-2/W6, 123–132.

Pommer, R. (1967). *Eighteenth-century architecture in Piedmont: The open structures of Juvarra, Alfieri & Vittone*. New York: New York University Press.

PTC Inc. (2020). *Tools Overview | VuforiaLibrary*. Retrieved February 25, 2021, from https://library.vuforia.com/tools/overview.html

Teruggi, S., Grilli, E., Russo, M., Fassi, F., Remondino, F. (2020). A Hierarchical Machine Learning Approach for Multi-Level and Multi-Resolution 3D Point Cloud Classification. *Remote Sensing*, 12, 2598.

Younes, G., Asmar, D., Elhajj, I., & Al-Harithy, H. (2017). Pose tracking for augmented reality applications in outdoor archaeological sites. *Journal of Electronic Imaging*, 26(1).

DOI: https://doi.org/10.20365/disegnarecon.26.2021.16